

CLAIMS

What is claimed is:

1. A method comprising:
disposing at least one solid diquatarnary ammonium salt including two positively-charged quaternary nitrogens spaced at a distance of less than about 10 Å into contact with an aqueous solution having multiple metal anion complexes including at least one target metal anion complex; and
separating from the aqueous solution an organo-metallic complex formed between the diquatarnary ammonium salt and the at least one target metal anion complex.
2. The method of claim 1, wherein the at least one diquatarnary ammonium salt exhibits greater binding specificity for the at least one target metal anion complex than for at least one other metal anion complex in the aqueous solution.
3. The method of claim 1, wherein the at least one diquatarnary ammonium salt exhibits selectivity for the at least one target metal anion complex.
4. The method of claim 1, wherein the at least one target metal anion complex is a metal halide.
5. The method of claim 4, wherein the at least one target metal halide complex has an ionic diameter between about 3 Å and about 5 Å.

6. The method of claim 1, wherein the at least one diquatery ammonium salt is selected from bis-octadecyl, methyl piperazine ammonium chloride; bis-decyl, methyl-piperazine ammonium chloride; dimethyl, octadecyl ethylene diammonium chloride; dimethyl, decyl ethylene diammonium chloride; dimethyl, octadecyl propyl diammonium chloride; dimethyl, decyl propyl diammonium chloride; dimethyl, octadecyl butyl diammonium chloride; dimethyl, decyl butyl diammonium chloride; dimethyl, octadecyl hexyl diammonium chloride; dimethyl, decyl hexyl diammonium chloride; bis-hydroxyethyl, octadecyl piperazine ammonium chloride; diethyl, octadecyl propyl diammonium chloride; bis-hydroxyethyl, eicosyl piperazine ammonium bromide; diethyl, eicosyl propyl diammonium bromide; bis-hydroxyethyl, docosyl piperazine ammonium bromide; and diethyl, docosyl piperazine diammonium bromide, and combinations thereof.
7. The method of claim 1, wherein the at least one diquatery ammonium salt includes a cyclical piperazine derivative.
8. The method of claim 1, wherein the at least one diquatery ammonium salt extracts the one or more metal anion complex at all acid concentrations.
9. The method of claim 1, wherein the at least one diquatery ammonium salt is essentially insoluble in the aqueous solution.
10. The method of claim 1, wherein the two quaternary nitrogens are coupled by a saturated alkyl chain.
11. The method of claim 1, wherein the two quaternary nitrogens are coupled by an unsaturated alkyl chain.

12. The method of claim 1, wherein the two quaternary nitrogens are coupled by a straight alkyl chain.
13. The method of claim 1, wherein the two quaternary nitrogens are coupled by a branched alkyl chain.
14. The method of claim 1, wherein the two quaternary nitrogens are coupled in a saturated heterocyclic ring structure.
15. The method of claim 27, wherein the two quaternary nitrogens are coupled in an unsaturated heterocyclic ring structure.
16. The method of claim 27, wherein the two quaternary nitrogens are coupled in a straight heterocyclic ring structure.
17. The method of claim 27, wherein the two quaternary nitrogens are coupled in a branched heterocyclic ring structure.
18. The method of claim 1, wherein the at least one diquaternary ammonium salt is a diquaternary ammonium halide.
19. The method of claim 18, wherein the diquaternary ammonium halide comprises a halide selected from iodide and chloride.
20. The method of claim 21, wherein the diquaternary ammonium halide comprises a halide selected from bromide and fluoride.

21. The method of claim 1, wherein the two quaternary nitrogens are coupled by an alkyl chain comprising between 2 and 6 methylene groups.
22. The method of claim 1, wherein the two quaternary nitrogens are separated by a distance between about 3 Å and about 8 Å.
23. The method of claim 1, wherein the distance between the two quaternary nitrogens is between about 5 Å less and 5 Å more than the size of the one or more metal anion complex to be selectively extracted.
24. The method of claim 1, wherein the quaternary nitrogens are substituted with alkyl chains that are branched, unbranched, saturated, unsaturated, aliphatic, aromatic, cyclic, noncyclic, or heterocyclic.
25. The method of claim 1, wherein the distance between the two quaternary nitrogens allows the formation of a complex between both quaternary nitrogens and the one or more metal anion complex to be selectively extracted.
26. The method of claim 1, further comprising:
forming a stable ion pair between the diquaternary ammonium salt and the metal anion complex.
27. The method of claim 1, wherein the one or more metal anion complex comprises one or more platinum group metal.
28. The method of claim 1, wherein the one or more metal anion complex is selected from anions of Pt, Pd, Rh, and combinations thereof.

29. The method of claim 28, wherein the multiple metal anion complexes comprise metals selected from Pb, Al, Ba, Ce, Zr, Fe, Cu, Cr, Co, Ni, Mo, Sn, Sb, As, Bi, Zn, Na, K, Ca and combinations thereof.
30. The method of claim 1, wherein the one or more metal anion complex comprises a metal selected from Ag, Au, Pd, Rh, Pt, Ru, Os, Ir, and combinations thereof.
31. The method of claim 1, wherein the at least one target metal anion complex is polyvalent.
32. The method of claim 31, wherein the polyvalent metal anion complex is a platinum group metal halide.
33. The method of claim 32, wherein the platinum group metal halide is selected from $[\text{PdCl}_4]^{2-}$, $[\text{PdCl}_6]^{3-}$, $[\text{PtCl}_4]^{2-}$, $[\text{PtCl}_6]^{2-}$, and combinations thereof.
34. The method of claim 1, wherein the aqueous solution is acidic.
35. The method of claim 1, wherein the aqueous solution includes an acid selected from hydrochloric acid, sulfuric acid, nitric acid and combinations thereof.
36. The method of claim 1, wherein the multiple metal anion complexes include Pd, Pt and Rh, and wherein the organo-metallic complex includes at least one platinum group metal selected from Pd, Pt, and Rh.

37. The method of claim 1, wherein the step of separating includes filtering the organo-metallic complex from the aqueous solution.
38. The method of claim 1, further comprising:
separating the target metal anions from the organo-metallic complex.
39. The method of claim 38, further comprising:
reusing the diquaternary ammonium salts for subsequent contact with an aqueous solution of one or more target metal anion complex.
40. The method of claim 38, wherein the target metal anions are separated from the organo-metallic complex by back-extracting the target metal anion complexes from the organo-metallic complex using a second aqueous acid solution.
41. The method of claim 38, wherein the step of separating the one or more target metal anion complexes from the organo-metallic complex includes electrodeposition of the target metal onto an electrode.
42. The method of claim 1, wherein the one or more target metal anion complex comprises a metal selected from Pd, Pt, Rh and combinations thereof, and wherein the two quaternary nitrogens are separated by an alkyl chain having 2 to 8 carbon atoms.
43. The method of claim 1, wherein the one or more target metal anion complex comprises a metal selected from Pd, Pt, Rh and combinations thereof, and wherein the two quaternary nitrogens are separated by an alkyl chain having 2 to 6 carbon atoms.

44. The method of claim 1, wherein the one or more target metal anion complex comprises a metal selected from Pd, Pt, Rh and combinations thereof, and wherein the two quaternary nitrogens are separated by an alkyl chain having 2 to 3 carbon atoms.

45. The method of claim 1, wherein the one or more metal anion complex comprises a metal selected from Pd, Pt, Rh and combinations thereof, and wherein the two quaternary nitrogens are part of a heterocyclic ring structure having 2 to 8 carbon atoms.

46. The method of claim 1, wherein the at least one solid diquaternary ammonium salt is immobilized on a substrate.

47. The method of claim 46, wherein the diquaternary ammonium salts are bound to a solid substrate by means selected from adsorption, absorption, chemical bonding, and combinations thereof.

48. The method of claim 47, wherein the solid substrate is selected from a monomer, polymer.

49. The method of claim 1, wherein the one or more solid diquaternary ammonium salt is particulate.

50. The method of claim 49, wherein the particulate is a powder.

51. A method for recovering Pd and Pt from a mixture of metals comprising:
dissolving the metals into an acidic solution to form metal anion complexes;
contacting the acidic solution with an iodide to form a Pd complex;
separating the Pd complex from the acidic solution using organic solvent extraction;
contacting the acidic solution with a solid diquatarnary ammonium salt, wherein the distance between two quaternary nitrogens is less than about 10 Å;
selectively binding the Pt anion complex to the diquatarnary ammonium salt; and
separating the aqueous solution from the diquatarnary ammonium salts having the bound Pt anion complex.
52. The method of claim 51, wherein the acidic solution contains acids selected from hydrochloric acid, sulfuric acid, nitric acid and combinations thereof.
53. A method for separating metals from a mixture of metals comprising:
a. dissolving the mixture of metals into an acidic solution to form metal anion complexes;
b. contacting the acidic solution with a first diquatarnary ammonium salt that is a selective extractant for a first metal anion complex to form a first organometallic complex;
c. separating the first organometallic complex from the aqueous solution;
d. contacting the acidic solution with a second diquatarnary ammonium salt that is a selective extractant for a second metal anion complex to form a second organometallic complex; and
e. separating the organometallic complex from the aqueous solution.
54. The method of claim 53, further comprising:
f. contacting the acidic solution with an iodide to form a Pd complex; and
g. separating the Pd complex from the acidic solution using organic solvent extraction.

55. The method of claim 24, wherein the diquatery ammonium salts are rendered insoluble in aqueous solutions.
56. The method of claim 1, wherein the at least one solid diquatery ammonium salts is a composite with another solid substrate.
57. The method of claim 47, wherein the solid substrate is selected from organic, inorganic and bioorganic.
58. The method of claim 1, wherein the one or more solid diquatery ammonium salt is formed as a membrane, coating, pellet, or bead.
59. The method of claim 1, wherein the at least one solid diquatery ammonium salt is mixed with another solid substrate.